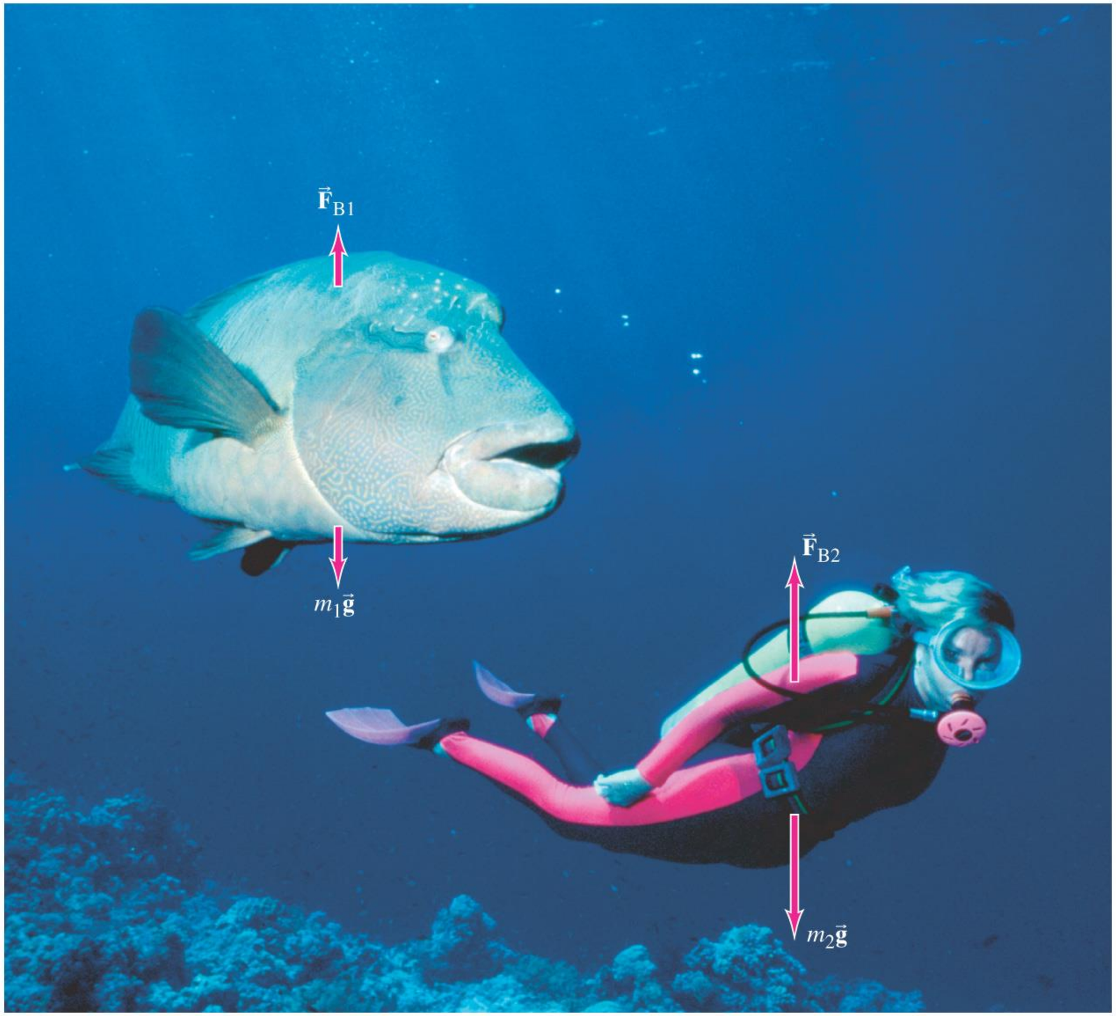
Chapter 10

Fluids



10-1 Phases of Matter

The three common phases of matter are **solid**, **liquid**, and **gas**.

A solid has a definite **shape** and **size**.

A liquid has a fixed **volume** but can be any shape.

A gas can be any shape and also can be easily **compressed**.

Liquids and gases both **flow**, and are called **fluids**.

10-2 Density and Specific Gravity

The **density** ρ of an object is its **mass** per unit **volume**:

$$\rho = \frac{m}{V} \qquad \text{(10-1)}$$

The SI unit for density is kg/m^3. Density is also sometimes given in g/cm^3; to convert g/cm^3 to kg/m^3, multiply by 1000.

Water at 4°C has a density of 1 g/cm^3 = 1000 kg/m^3.

The **specific gravity** of a substance is the ratio of its density to that of water.

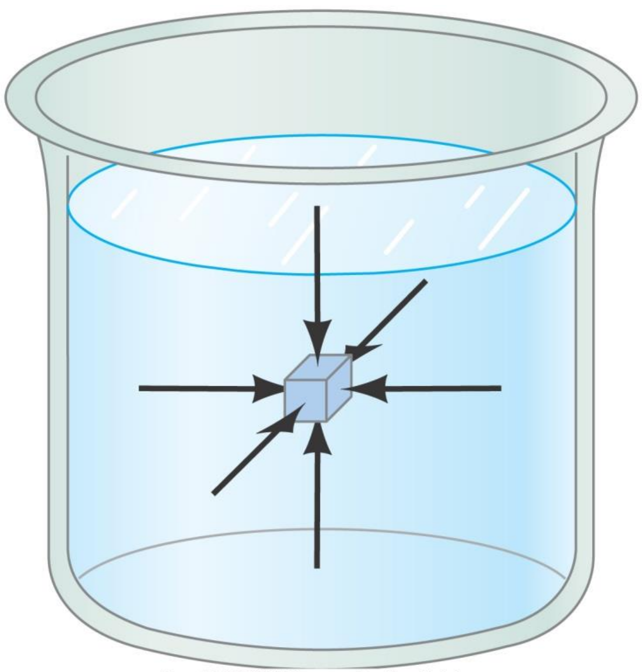
10-3 Pressure in Fluids

Pressure is defined as the **force** per unit **area**.

$$pressure = P = \frac{F}{A}$$

Pressure is a scalar; the units of pressure in the SI system are **pascals**:

1 Pa = 1 N/m^2



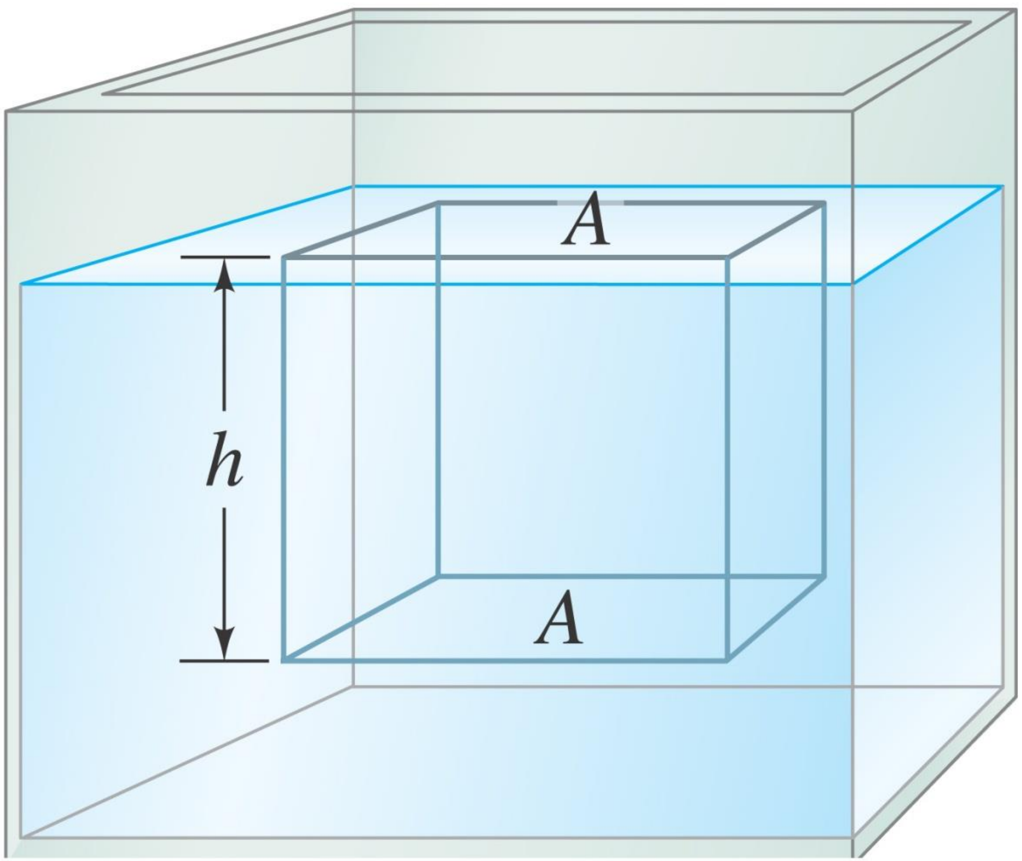
Pressure is the same in every **direction** in a fluid at a given **depth**; if it were not, the fluid would flow.

Example 10-2

- The two feet of a 60 kg person cover an area of 500 square centimeters
  - Determine the pressure exerted with two feet on the ground
  - Determine the pressure if the person stands on one foot.

10-3 Pressure in Fluids

The **pressure** at a depth *h* below the surface of the liquid is due to the **weight** of the liquid above it. We can quickly calculate:



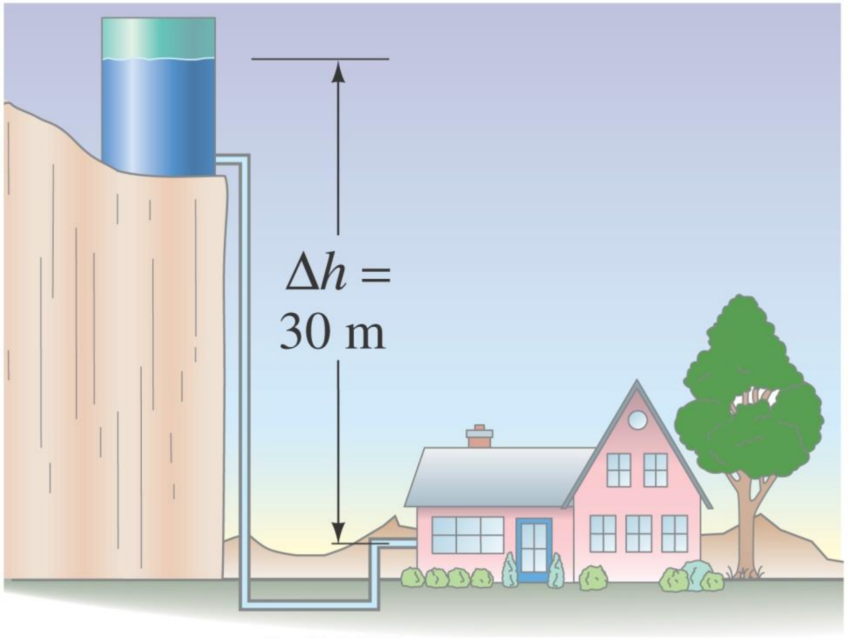
$$P = \rho g h \tag{10-3}$$

This relation is valid for any liquid whose density does not change with depth.

Note: The area does not affect the pressure.

Example 10-3

- The surface of the water in a storage tank is 30m above the faucet in a house. Calculate the difference in water pressure between the tank and the faucet.



10-4 Atmospheric Pressure and Gauge Pressure

At **sea level** the **atmospheric** pressure is about $1.013 \times 10^5\ \mathrm{N/m^2}$; this is called one **atmosphere** (**atm**).

$$1\,\mathrm{atm} = 1.013 \times 10^5\ \mathrm{N/m^2} = 101.3\,\mathrm{kPa}$$

Another unit of pressure is the bar:

$$1\ \mathrm{bar} = 1.00 \times 10^5\ \mathrm{N/m^2}$$

Standard atmospheric pressure is just over 1 bar.

This pressure does not **crush** us, as our cells maintain an internal pressure that balances it.

10-4 Atmospheric Pressure and Gauge Pressure

Most **pressure gauges** measure the pressure **above** the atmospheric pressure – this is called the **gauge pressure**.

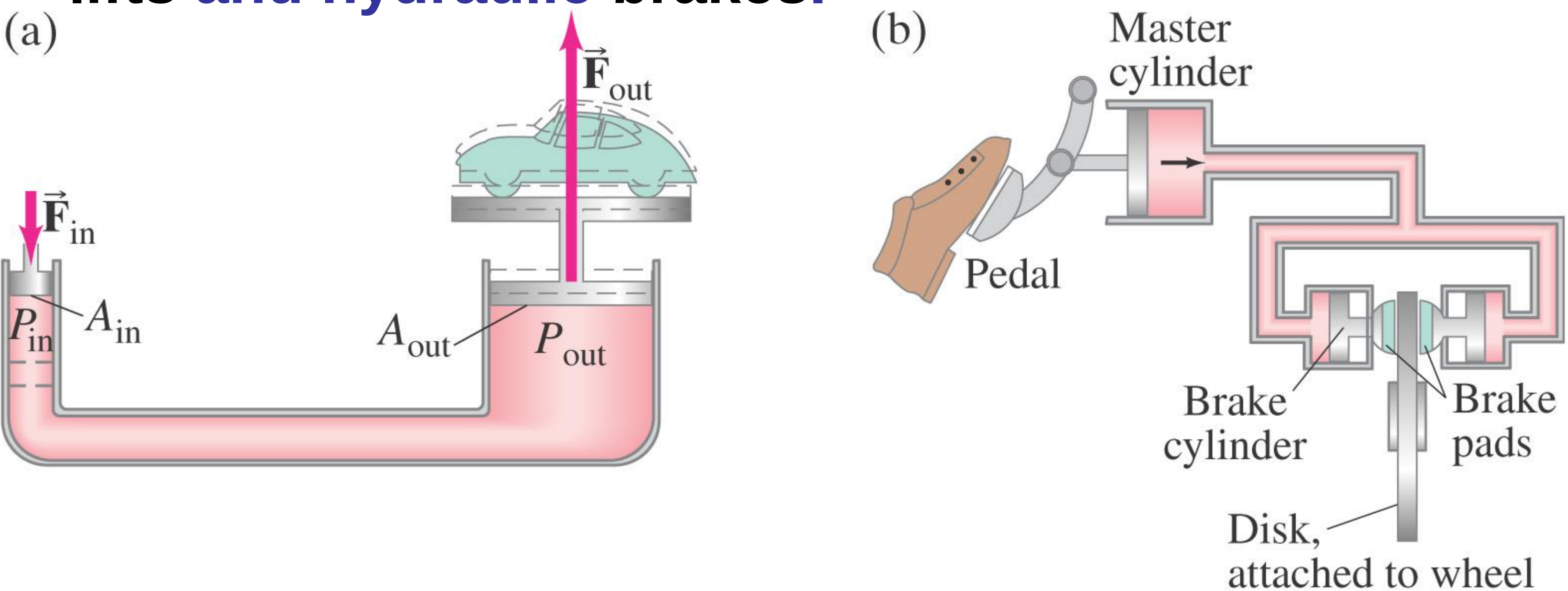
The **absolute pressure** is the sum of the atmospheric pressure and the gauge pressure.

$$P = P_{\mathrm{A}} + P_{\mathrm{G}}$$

10-5 Pascal's Principle

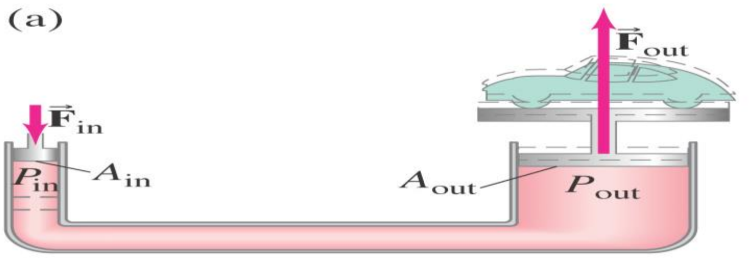
If an **external** pressure is applied to a **confined** fluid, the pressure at **every** point within the fluid increases by that amount.

This principle is used, for example, in hydraulic **lifts** and hydraulic **brakes**.



Mechanical Advantage with Pascal's Principle

- One example of a practical device is the hydraulic lift.
- The quantity F_{out}/F_{in} is called the mechanical advantage.
  - If the area of the output piston is 20 times the area of the input cylinder, a 400N force could lift a 8000N Car



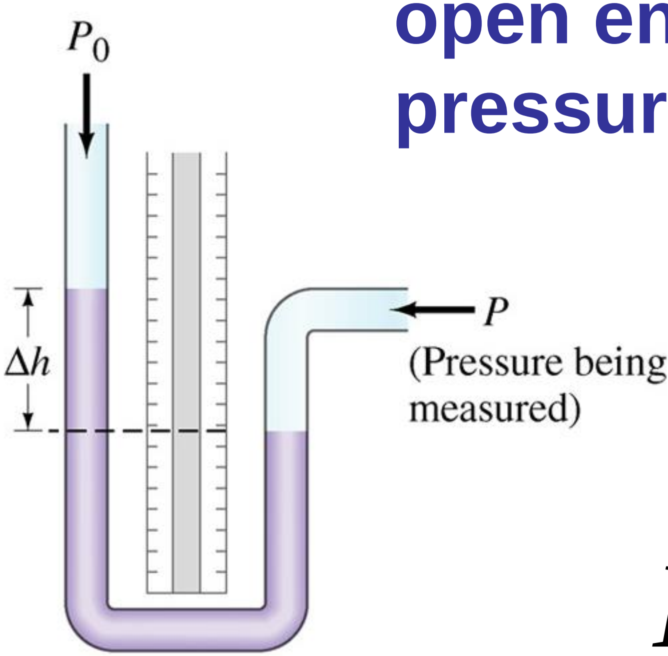
$$P_{out} = P_{in}$$

$$\frac{F_{out}}{A_{out}} = \frac{F_{in}}{A_{in}}$$

$$\frac{F_{out}}{F_{in}} = \frac{A_{out}}{A_{in}}$$

10-6 Measurement of Pressure; Gauges and the Barometer

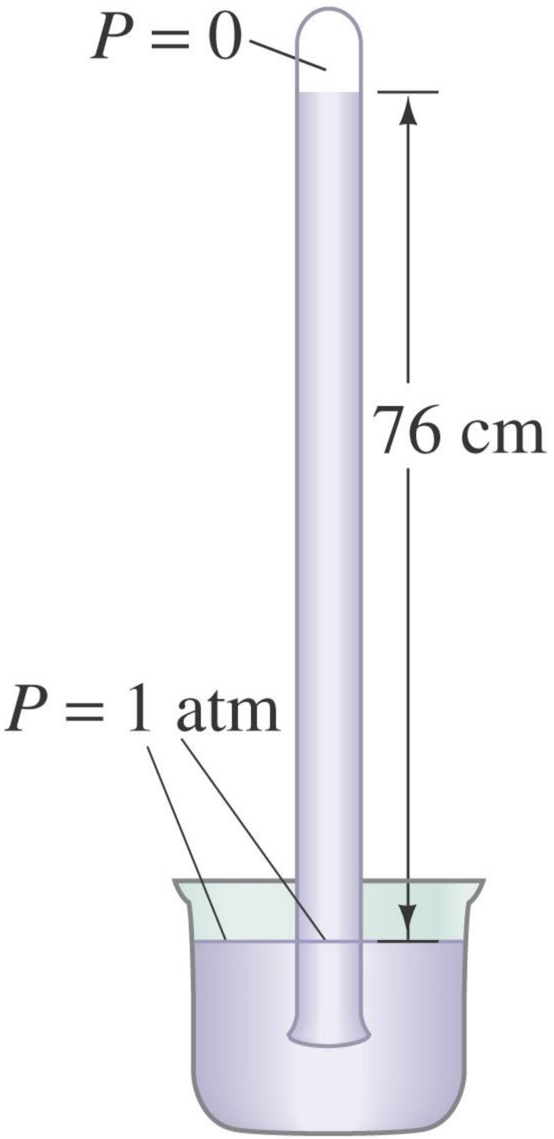
There are a number of different types of **pressure gauges**. This one is an open-tube **manometer**. The pressure in the open end is **atmospheric** pressure; the pressure being measured will cause the fluid to **rise** until the pressures on both sides at the same height are **equal**.



(a) Open-tube manometer

$$P = P_0 + \rho g \Delta h$$

10-6 Measurement of Pressure; Gauges and the Barometer



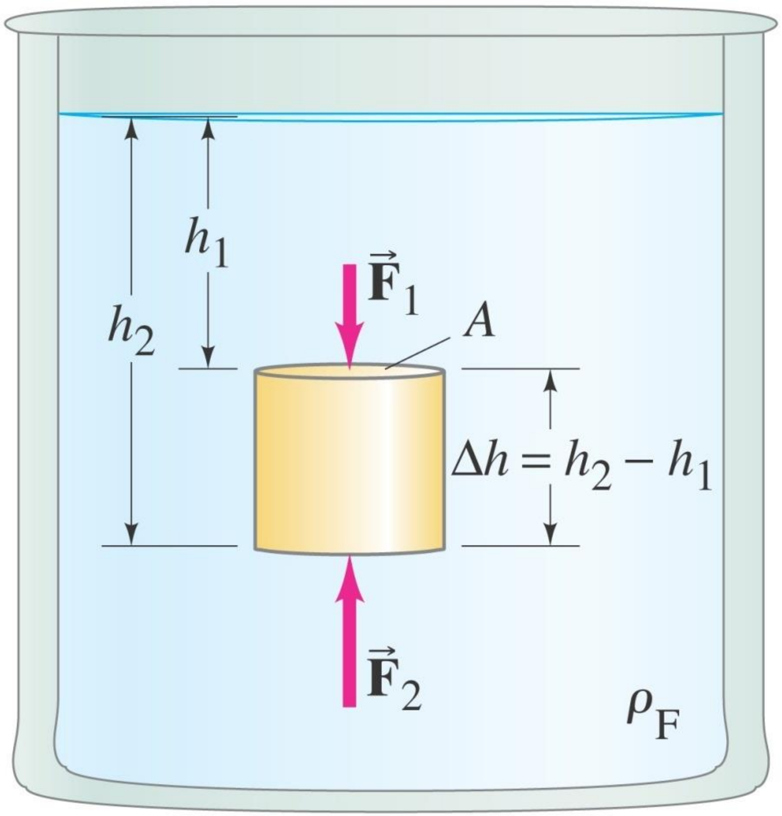
This is a **mercury** barometer, developed by Torricelli to measure **atmospheric pressure**. The **height** of the column of **mercury** is such that the pressure in the tube at the surface level is 1 atm.

Therefore, pressure is often quoted in **millimeters** (or inches) of mercury.

$$P = \rho g \Delta h$$

10-7 Buoyancy and Archimedes' Principle

This is an object **submerged** in a fluid. There is a net **force** on the object because the pressures at the top and bottom of it are different.

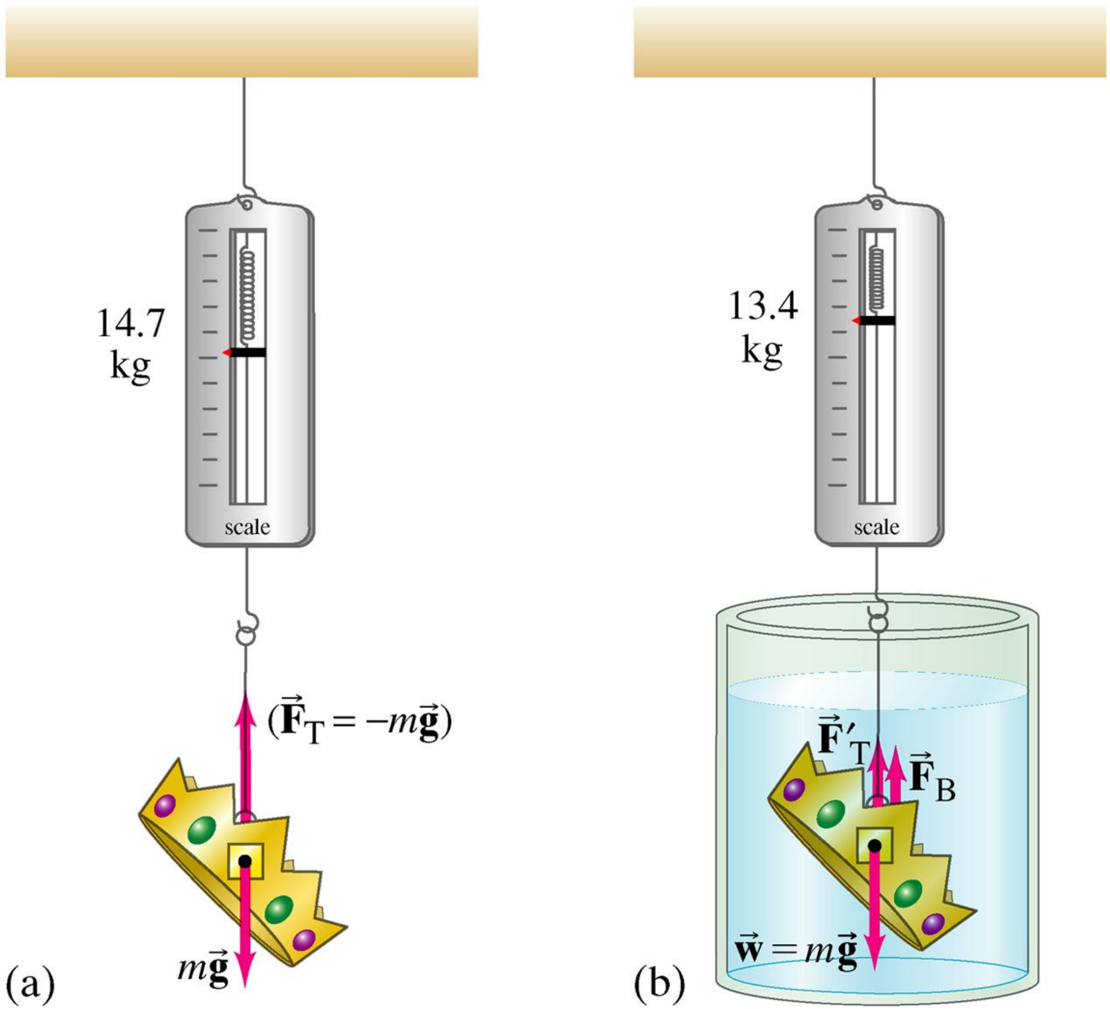


The **buoyant force** is found to be the **upward** force on the **same** volume of water:

$$
\begin{aligned}
F_B = F_2 - F_1 &= \rho_F g A (h_2 - h_1) \\
&= \rho_F g A \Delta h \\
&= \rho_F V g \\
&= m_F g,
\end{aligned}
$$

10-7 Buoyancy and Archimedes' Principle

The **net force on** the object is then the difference between the **buoyant force** and the **gravitational force.**



Example 10-7

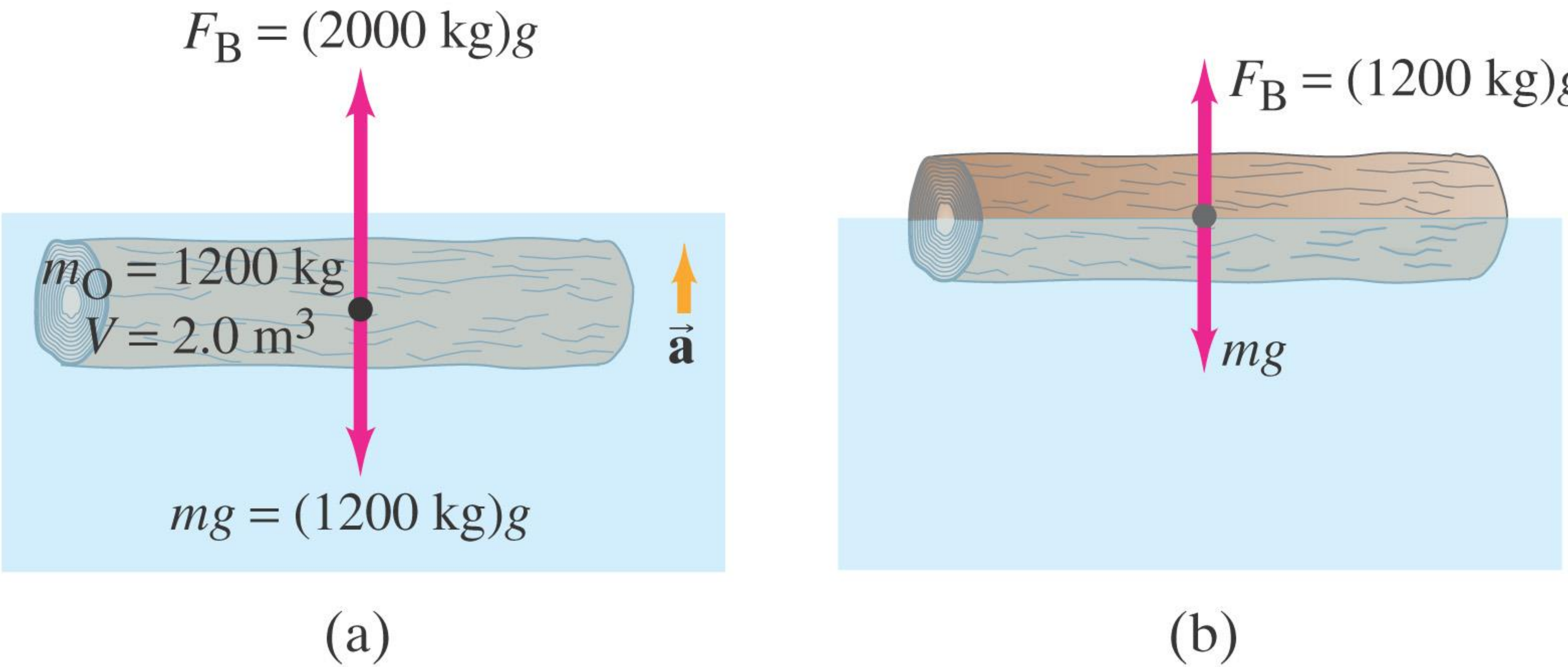
- A 70kg statue lies at the bottom of the sea. If has a volume of 3.0×10^4 cm^3. How much force is needed to lift it? (ρ for seawater = 1.025×10^3 kg/m^3)

Example 10-8

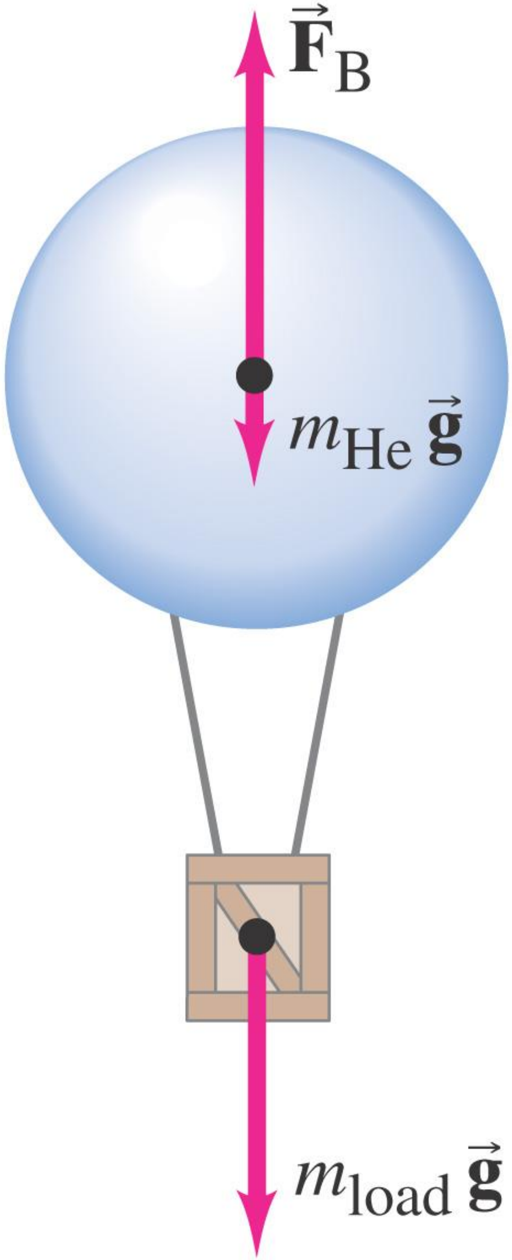
- When a crown of mass 14.7 kg is submerged in water, an accurate scale reads 13.4 kg. Is the crown made of gold?

10-7 Buoyancy and Archimedes' Principle

If the object's **density** is **less** than that of water, there will be an **upward** net force on it, and it will rise until it is partially **out** of the water.



10-7 Buoyancy and Archimedes' Principle



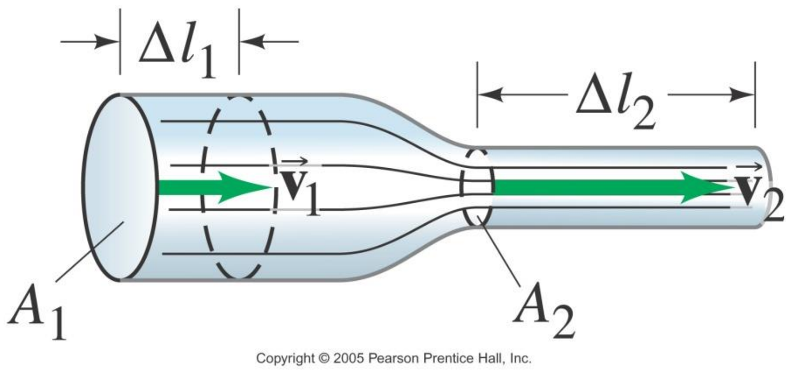
This principle also works in the air; this is why hot-air and helium balloons rise.

Example 10-10

What volume of helium is needed to lift a load of 180kg including the weight of the empty baloon?

10-8 Fluids in Motion; Flow Rate and the Equation of Continuity

$$\text{mass flow rate} = \frac{\Delta \text{m}}{\Delta \text{t}}$$



$$\frac{\Delta \text{m}}{\Delta \text{t}} = \frac{\rho \Delta V}{\Delta t} = \frac{\rho A \Delta l}{\Delta t} = \rho A v$$

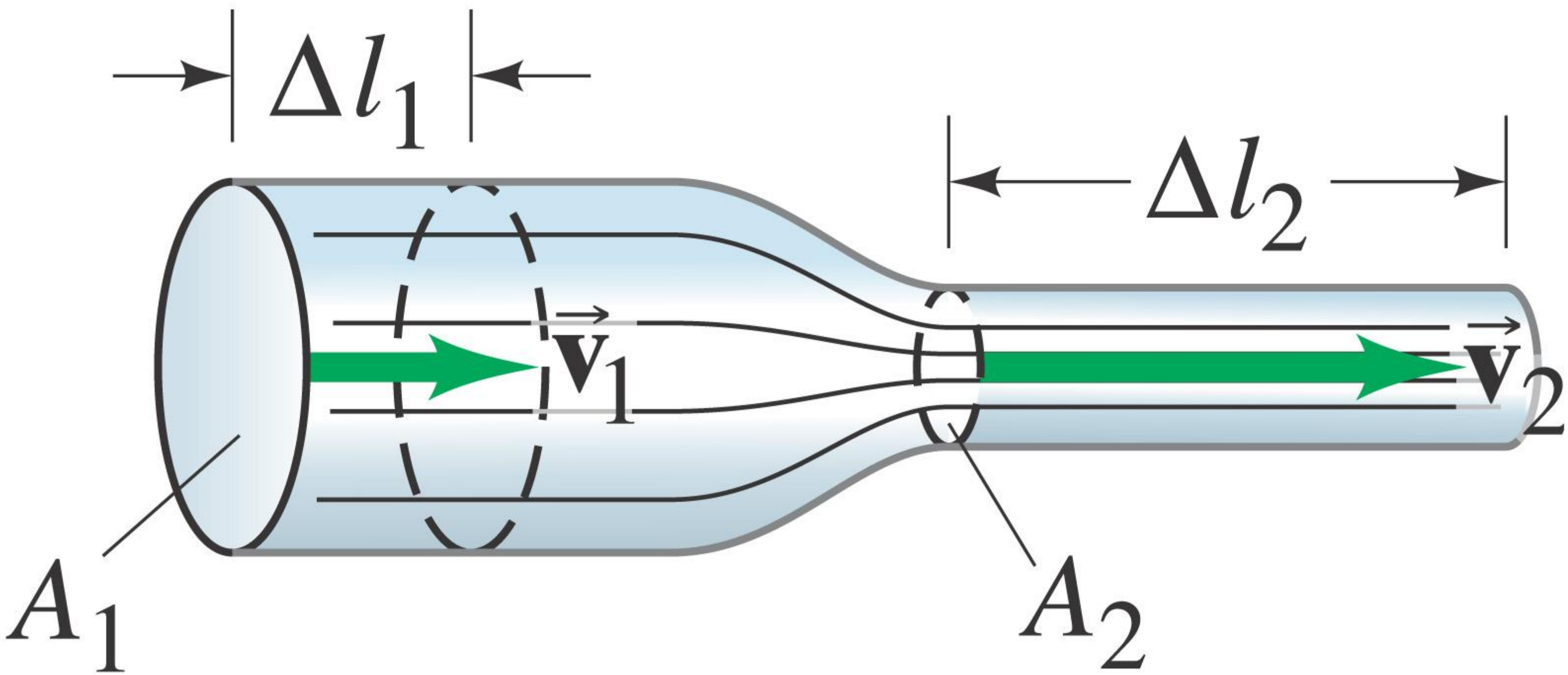
This gives us the equation of continuity:

$$\rho_1 A_1 v_1 = \rho_2 A_2 v_2$$

10-8 Fluids in Motion; Flow Rate and the Equation of Continuity

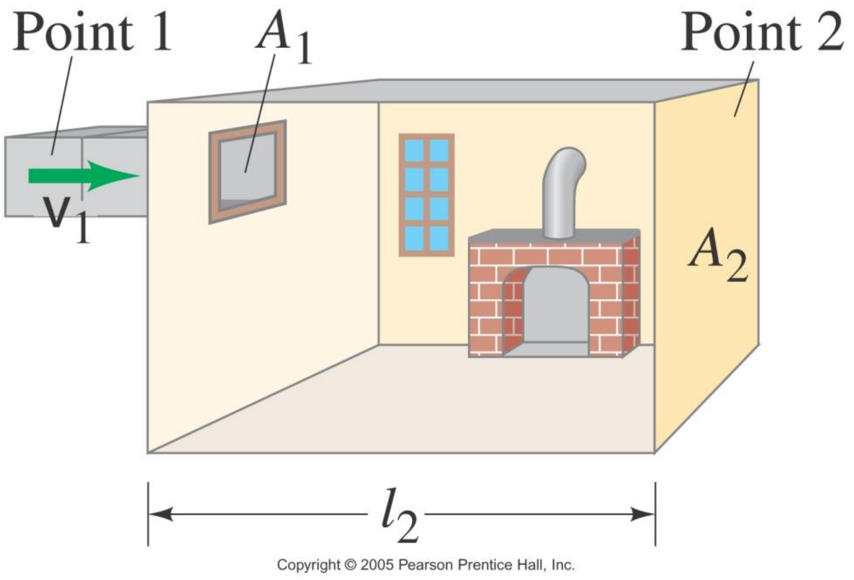
If the density doesn't change – typical for liquids – this simplifies to $A_1 v_1 = A_2 v_2$.

Where the pipe is wider, the flow is slower.

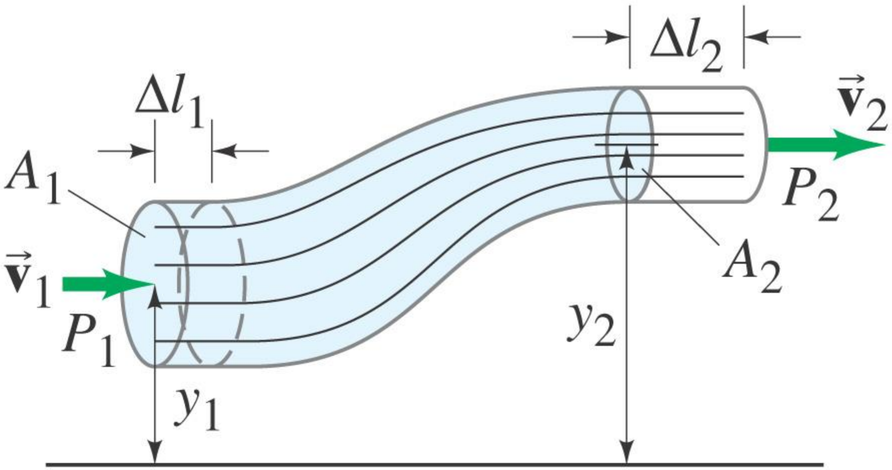


Example 10-12

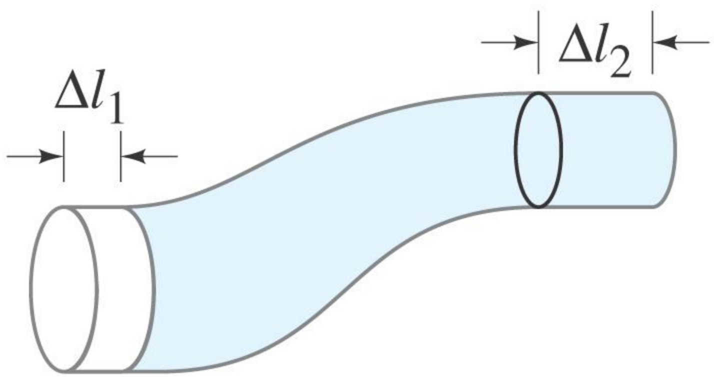
- What area must a heating duct have if air moving 3 m/s along it can replenish the air every 15 minutes in a room of 300 cubic meters volume?



10-9 Bernoulli's Equation



(a)



(b)

A fluid can also change its **height**. By looking at the work done as it moves, we find:

$$P + \frac{1}{2}\rho v^2 + \rho g y = \text{constant}$$

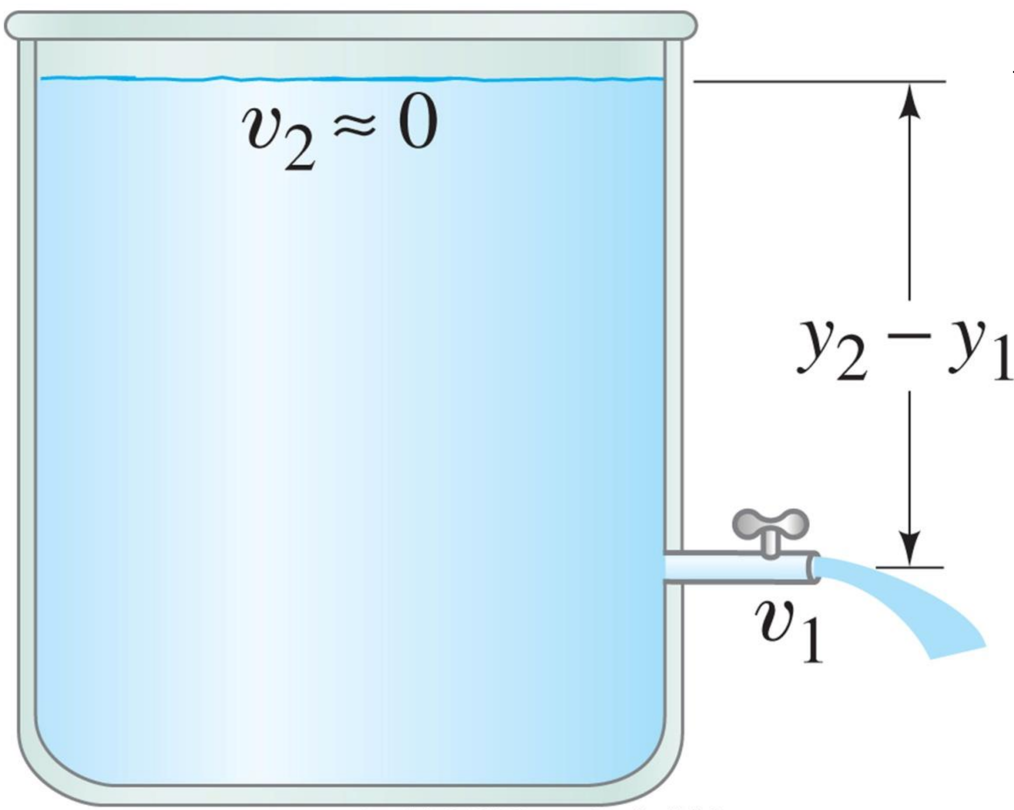
This is **Bernoulli's equation**. One thing it tells us is that as the **speed** goes up, the **pressure** goes down.

Example 10-13

- Water circulates through a house in a hot water heating system. If the water is pumped at a speed of 0.5 m/s through a 4cm pipe in the basement at a pressure of 3.0 atm, what will be the flow speed and pressure in a 2.6cm pipe on the 2^{nd} floor 5 meters above?

10-10 Applications of Bernoulli's Principle: from Torricelli to Airplanes, Baseballs, and TIA

Using Bernoulli's principle, we find that the speed of fluid coming from a **spigot** on an **open** tank is:

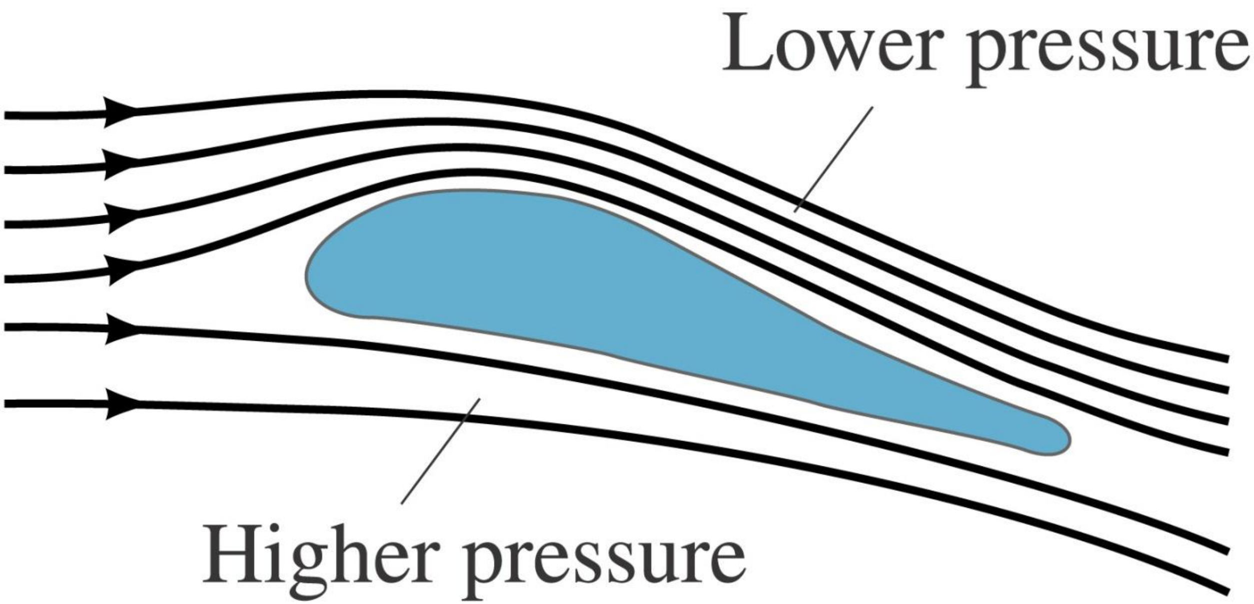


$$v_1 = \sqrt{2g(y_2 - y_1)} \quad \text{(10-6)}$$

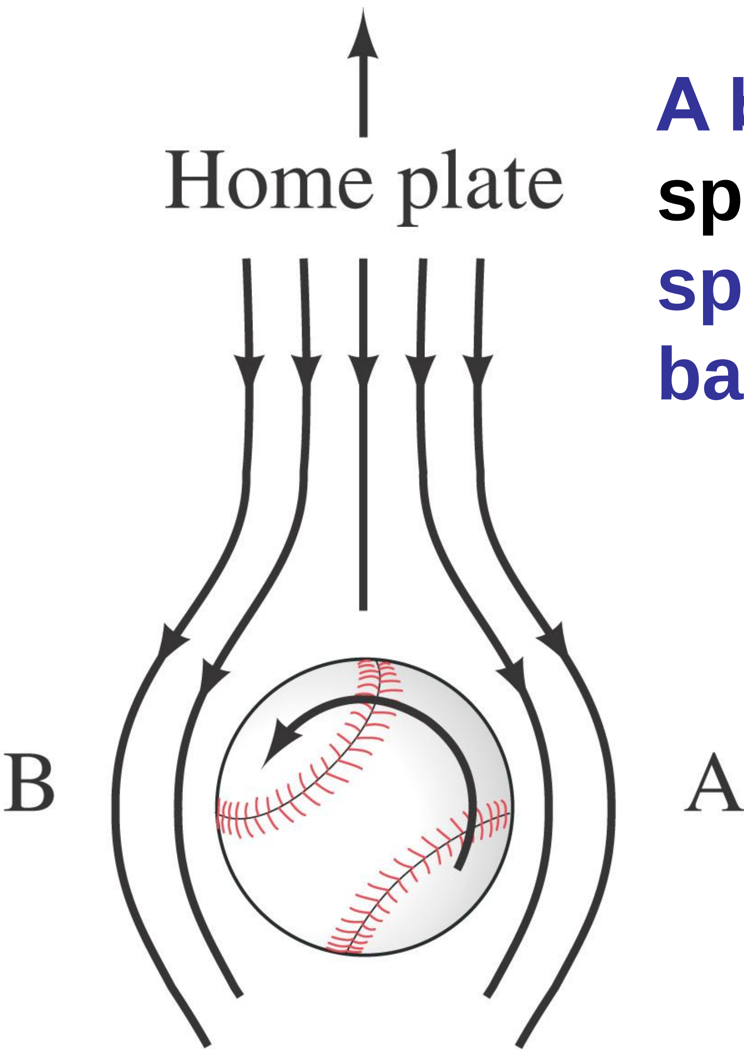
This is called **Torricelli's** theorem.

10-10 Applications of Bernoulli's Principle: from Torricelli to Airplanes, Baseballs, and TIA

Lift on an airplane **wing** is due to the different air **speeds** and **pressures** on the two surfaces of the wing.



10-10 Applications of Bernoulli's Principle: from Torricelli to Airplanes, Baseballs, and TIA



A ball's path will **curve** due to its **spin**, which results in the air speeds on the two sides of the ball not being equal.

10-10 Applications of Bernoulli's Principle: from Torricelli to Airplanes, Baseballs, and TIA

A **venturi meter** can be used to measure fluid **flow** by measuring **pressure** differences.